1307

Met.O.905
METEOROLOGICAL OFFICE

the meteorological magazine

JUNE 1977 No 1259 Vol 106
Her Majesty's Stationery Office

METEOROLOGICAL OFFICE Met.O.905

THE METEOROLOGICAL MAGAZINE

Vol. 106, No. 1259, June 1977

551.501.3: 551.547.5

A FURTHER COMPARISON OF 50-MILLIBAR GEOPOTENTIALS OBTAINED FROM SATELLITE INFRA-RED SPECTROMETER SOUNDINGS AND ANALYSED CHARTS

By V. BAILEY

SUMMARY

In March 1975 the National Oceanic and Atmospheric Administration (NOAA) introduced a 'regression' method of retrieving Satellite Infra-red Spectrometer (SIRS) temperature profiles from Vertical Temperature Profile Radiometer (VTPR) data. Comparisons of 50 mb SIRS geopotentials with those derived from a series of 50 mb charts, based upon radiosonde data, have been carried out for the period 25 August 1975 to 12 April 1976. Although the quality of the SIRS data is still rather variable, there has been a marked reduction in bias errors and some decrease in the standard deviation of the SIRS minus analysed differences since the new retrieval method became operational in August 1975, especially over the Atlantic and southern North Pacific Oceans. However, north of 50°N in the Pacific, a bias error persists.

In a previous comparison of 50 mb geopotentials from Satellite Infra-red Spectrometer (SIRS) soundings and analysed charts, which covered the period June 1974 to May 1975 (Watson and Bailey, 1976), the quality of the SIRS data was found to be very variable. The mean SIRS minus analysed differences displayed a marked latitude dependence, the SIRS geopotentials being comparable to the analysed geopotentials at 60°N and about 10 geopotential decametres too high between 20° and 30°N. The mean difference varied with time, with discontinuities whenever the instrument or spacecraft, or both, changed. It was noted in that paper that a new technique to produce the SIRS thicknesses from observed Vertical Temperature Profile Radiometer (VTPR) radiances was introduced by the National Oceanic and Atmospheric Administration (NOAA) on 13 March 1975. In this technique (Hayden, 1976) each thickness is derived from a regression equation involving the deduced clear-column radiances for several VTPR channels.

The regression coefficients were derived from an analysis of co-located radiosonde and SIRS observations. These coefficients were initially calculated

from comparisons made during January and February 1975 and subsequently updated on 21 August 1975 with collocations made in June and August. It is understood that, since this date, there has been no change of coefficients or methods. Instrument No. 2 on NOAA 4 was in use throughout the period of this study. Indeed, it has been learnt that, contrary to Figure 1 of Watson and Bailey (1976), instrument No. 2 on NOAA 4 was brought into use from December 1974. Thus the abrupt decrease in mean differences in March 1975 was solely the consequence of introducing the regression method for deducing SIRS thicknesses.

For this present investigation, comparisons have been made on 34 occasions, seven days apart, during the period 25 August 1975 to 12 April 1976. The method of comparison was similar to that used in the previous investigation; values were taken from a daily (00 GMT) series of northern hemisphere 50 mb charts, drawn up using radiosonde data only. Comparisons were made for SIRS observations made within ± 3 hours of 00 GMT and therefore were confined to the Atlantic and western Pacific Oceans. The average number of SIRS minus analysed differences on each occasion was 33, with a maximum of 47 and a minimum of 15. It was found that the two populations of differences for the Atlantic and Pacific respectively were significantly different at the 1 per cent level. Figure 1 shows the mean differences, together with the standard errors of the means, at intervals of seven days for both areas. The average of the mean differences for the Atlantic was $+1{\cdot}0$ geopotential decametres and for the Pacific

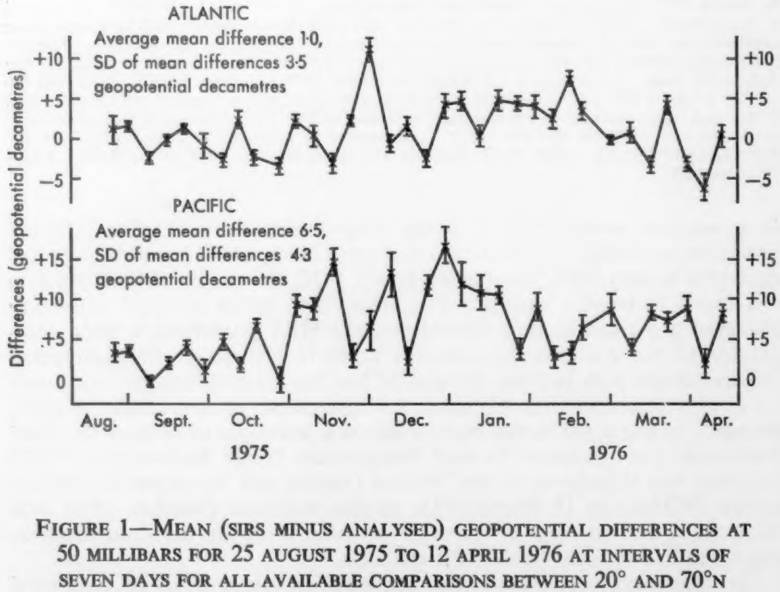

FIGURE 1—MEAN (SIRS MINUS ANALYSED) GEOPOTENTIAL DIFFERENCES AT 50 MILLIBARS FOR 25 AUGUST 1975 TO 12 APRIL 1976 AT INTERVALS OF SEVEN DAYS FOR ALL AVAILABLE COMPARISONS BETWEEN 20° AND 70°N

Vertical bars indicate standard errors of means.

+6·5 geopotential decametres. The increased variability of the mean differences for the winter months when compared with autumn is particularly noticeable.

For the Atlantic area, an examination of the data for the period August 1975 to April 1976 in 10° latitude bands showed (bottom plot of Figure 2) the variation of the mean difference with latitude to be small. It varied from 1·8 geopotential decametres between 20° and 30°N to −0·6 between 40° and 50°N and 2·8 between 60° and 70°N. In order to assess the impact of the change of retrieval method directly, data for part of the previous study period (15 December 1974 to 13 March 1975) have been reanalysed. During the latter period, the same instrument (No. 2) on NOAA 4 was being used but SIRS values were being derived by the 'minimum information method'. These results are included in Figure 2. The current regression method of retrieval has considerably suppressed the variation with latitude and eliminated the systematic error at the 50 mb level.

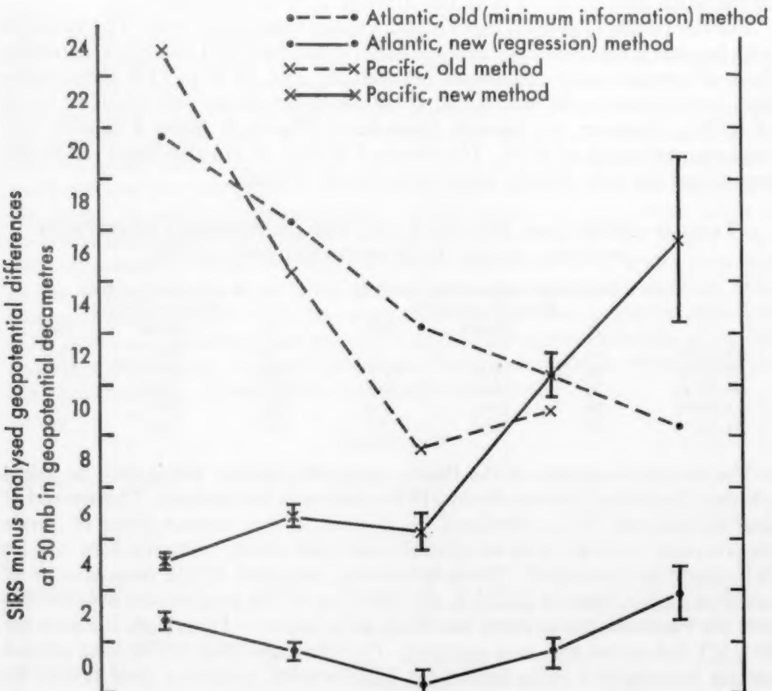

FIGURE 2—VARIATION WITH LATITUDE OF THE MEAN DIFFERENCES OF GEOPOTENTIAL BETWEEN SIRS AND ANALYSED DATA

Vertical bars indicate standard errors of means.

The data for these two periods are summarized in Table I. *N* is the number of observations.

TABLE I—50-MILLIBAR SIRS MINUS ANALYSED GEOPOTENTIAL DIFFERENCES OVER THE ATLANTIC (IN GEOPOTENTIAL DECAMETRES)

	Minimum information method 15/12/74–13/3/75			Regression method 25/8/75–12/4/76		
	N	Mean	SD	*N*	Mean	SD
60–70°N	56	9·4	9·4	104	2·8	9·8
50–60°N	83	11·4	10·0	203	0·6	8·6
40–50°N	80	13·3	10·9	239	−0·6	7·3
30–40°N	104	17·3	13·9	339	0·7	6·3
20–30°N	61	20·6	11·3	260	1·8	4·3

Using the standard deviation (SD) as a measure of variability of the differences, the Table suggests that there has been a considerable improvement in the quality of the SIRS data at 50 mb over the Atlantic at lower latitudes.

For the Pacific (Table II) there is still a mean systematic error. The variation with latitude is also more marked, the SIRS minus analysed difference increasing from 4·1 geopotential decametres between 20° and 30°N to 11·3 geopotential decametres between 50° and 60°N. (Only 14 observations were available north of 60°N.) However, the latitude dependence (Figure 2) shows a considerable improvement south of 50°N. The standard deviations are also improved in this region and are only slightly larger than for the Atlantic.

TABLE II—50-MILLIBAR SIRS MINUS ANALYSED GEOPOTENTIAL DIFFERENCES OVER THE PACIFIC (IN GEOPOTENTIAL DECAMETRES)

	Minimum information method 15/12/74–13/3/75			Regression method 25/8/75–12/4/76		
	N	Mean	SD	*N*	Mean	SD
60–70°N	—	—	—	14	16·6	11·9
50–60°N	76	9·9	11·9	166	11·3	11·4
40–50°N	78	8·5	8·9	193	5·3	9·6
30–40°N	90	15·4	8·9	227	5·8	7·4
20–30°N	87	23·9	7·7	267	4·1	5·2

The bias in the north of the Pacific area still persists, but it may be asked whether this reflects an error in the SIRS values or in the analysis. The method of analysis requires that corrections be applied to the various types of sonde observations to make them compatible with each other, using the Kew Mk 2b radiosonde as a standard. These corrections, obtained by the comparisons of sondes with the objective analysis, are small (up to −4 geopotential decametres) over the Pacific in low latitudes but fairly large (up to −11) in high latitudes for 00 GMT (when this area is in sunlight). Campbell and May (1976) have carried out an investigation using co-located SIRS/sondes, analysing their results by types of sonde. In relation to the Kew sonde, they found differences which, while having the same sign as the corrections that we apply in our chart analysis, were smaller. For instance, they found that the mean difference (in geopotential decametres) between the Kew sonde and the Russian sonde was approximately 3 for the 1000–100 mb thickness, which would correspond to about 4 for the 1000–50 mb thickness, compared with the correction of 11 applied during chart analysis. Use of the Campbell and May figures would greatly reduce the latitude dependence in the north of the Pacific area. This, of course, assumes that SIRS

values are in some way more consistent than radiosonde values in judging the difference between sondes at night over the Atlantic and in daylight over the Pacific. The only sonde for which Campbell and May were able to investigate differences between day and night was the Japanese sonde. Their findings were that the SIRS minus analysed values were 3·9 geopotential decametres greater by night than by day, in close agreement with 4·7 obtained from the objective analysis scheme. This result suggests that SIRS soundings for a given location do not show any significant day-to-night difference. However, other possibilities exist in the SIRS analysis for the introduction of bias between the Atlantic and the Pacific. NOAA uses several sets of regression coefficients, selected by values of observed clear-column radiances in the window channel and a channel (No. 2) with a weighting function in the stratosphere. The climatic difference between the North Pacific and North Atlantic temperatures at low stratospheric levels (Labitzke *et alii*, 1972) presumably causes a bias towards different sets of coefficients for the production of SIRS values for the North Pacific and North Atlantic. This is something that the ordinary user of SIRS soundings cannot check without also accessing the clear-column radiance data.

In conclusion, it is clear that there has been a marked improvement in quality of SIRS geopotential estimates at 50 mb since the regression method of retrieval was introduced, mainly because of the reduction in bias error for the Atlantic and southern North Pacific. For the northern part of the Pacific area our analysis suggests either that there is a bias error in some of NOAA's sets of regression coefficients or that our present estimates of sonde corrections over the north of the Pacific in daylight are misleading. Continuation of the present form of comparison of SIRS values with the analysed charts is now no longer valid. This is because the 50 mb charts are constructed from a 100 mb chart, produced in the Central Forecasting Office, which now contains an element of SIRS observations. Hooper (1975) has suggested that satellite radiances calculated from upper-air soundings may provide a useful basis for comparison of sondes. Studies of SIRS minus analysed differences will be continued in order to improve the understanding of both SIRS and sonde behaviour.

References

CAMPBELL, J. S. and MAY, B. R. 1976 Some results of comparisons of thickness and temperature from radiosonde and SIRS soundings. Proceedings of the COSPAR Symposium on Meteorological Observations from Space: their Contributions to the First GARP Global Experiment, Philadelphia, Pa, USA, June 1976, pp. 70–76.

HAYDEN, C. M. 1976 The use of the radiosonde in deriving temperature soundings from the NIMBUS and NOAA satellite data. *NOAA Tech Mem* NESS 76, Washington, DC.

HOOPER, A. H. 1975 Upper-air sounding studies, Vol. I, Studies on radiosonde performance. *Tech Notes, Wld Met Org*, Geneva, No. 140, pp. 1–109.

LABITZKE, K. *et alii* 1972 Climatology of the stratosphere in the northern hemisphere, Part I. *Met Abh, Berlin*, **100**, Heft 4.

WATSON, N. R. and BAILEY, V. 1976 Comparison of 50-millibar geopotentials derived from satellite infra-red spectrometer readings with those derived from a series of analysed charts. *Met Mag*, **105**, pp. 105–109.

551.509.324.2(547): 551.554

A NUMERICAL INDEX TO MONITOR THE AFRO-ASIAN MONSOON DURING THE NORTHERN SUMMERS

By J. FINDLATER*

SUMMARY

The identification of the core of the major low-level air current of the Afro-Asian summer monsoon at a topographically fixed position over eastern Africa has allowed an attempt to be made to monitor the low-level flow and relate it to rainfall downstream over western India. An index of the southerly flow over eastern Africa at a station a few degrees south of the Equator for the month of July, for a period of 24 years, is compared with the July rainfall of ten stations in the western part of the State of Maharashtra, India.

It is found that months with an index of high or low wind correspond well with months of high or low rainfall respectively, especially when two-year overlapping averages are used. An interesting feature of the analysis is that there is a one-year lag between maxima and minima of the wind index over eastern Africa and the corresponding features of the rainfall of western India. A tentative calculation is made to illustrate how the lag might be used for long-range rainfall prediction.

1. INTRODUCTION

It has been reported earlier (Findlater, 1969a, 1969b and 1971) that the low-level airflow of the Afro-Asian summer monsoon is organized into a narrow high-speed current circulating at about 1·5 km above mean sea level in the western periphery of the monsoon system. A simplified map of the mean flow at 1 km for the month of July is shown in Figure 1, and it is noticeable that the core of the current, though primarily an oceanic phenomenon, passes over the flat arid lands of eastern Kenya, eastern Ethiopia and Somalia.

It was over these land areas that low-level jet streams, with speeds reaching 25–50 m/s, were first noticed some years ago (Findlater, 1966 and 1967). These low-level jet streams, or surges in the major current, have been located over the ocean as well as over land—usually in the vicinity of the axis of maximum flow shown in Figure 1 and orientated along it.

The fact that the axis of the major current passes over land was used in an earlier analysis to monitor the flow at an equatorial station in eastern Africa and, when five-day overlapping means were used, a close relationship between pulsations of the flow over eastern Africa and fluctuations in the rainfall of western India was noticeable (Findlater, 1969a). Similar but unpublished analyses for some other years have confirmed this relationship. It should be noted, however, that the correspondence between cross-equatorial flow over eastern Africa and the rainfall of western India can only be located if the upper-wind stations which are used lie under or very close to the core of the current shown in Figure 1. Attempts to use radar-wind data from Nairobi (01°18′S, 36°45′E, 1798 m above mean sea level) or Dar es Salaam (06°53′S, 39°12′E, 55 m) have proved fruitless because Nairobi is not affected by the current and Dar es Salaam lies on the fringe of it and is distant from the core. Recourse must be had to pilot-balloon data, and the earlier analysis used data from Garissa (00°29′S, 39°38′E, 128 m), a station almost on the Equator and close to the core of the current.

* At present on secondment from the Meteorological Office to the East African Meteorological Department, Nairobi, Kenya.

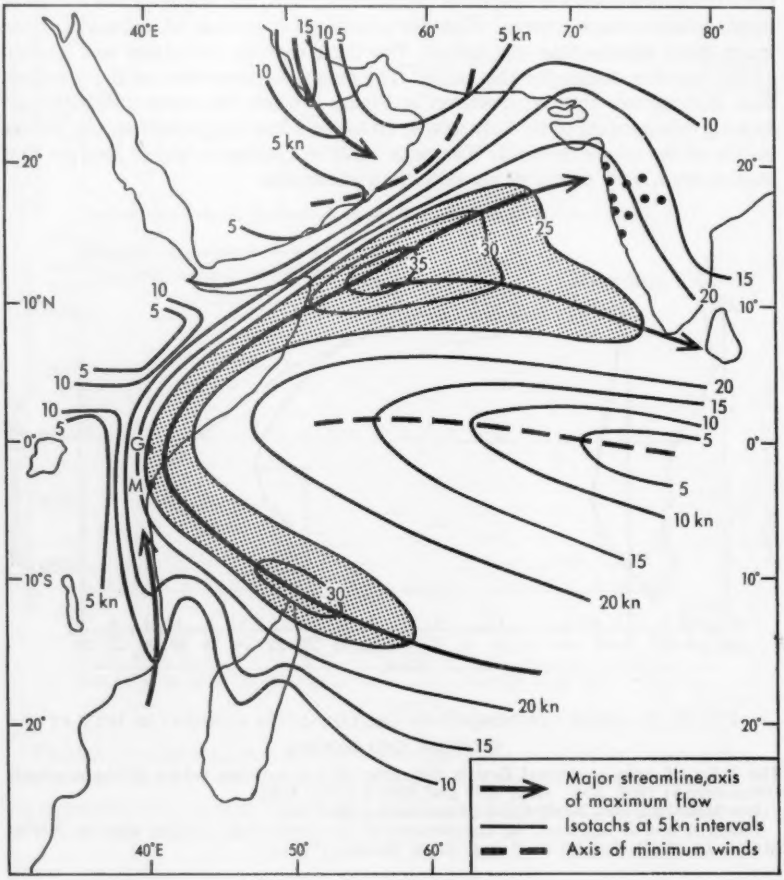

FIGURE 1—MEAN MONTHLY AIRFLOW AT 3000 ft (1 km) IN JULY
M—Mombasa G—Garissa
(The dots over India represent the ten selected rainfall stations.)

The aim of this present study is to monitor the flow over eastern Africa, using mean values for the month of July from as many years as possible, to compare the vigour of the monsoon from year to year and to relate it to the mean July rainfall downstream over western India.

2. SELECTION OF A MONITORING PARAMETER

Although the pilot-balloon station at Garissa is ideally situated for monitoring the flow at the core of the major current where it crosses the Equator, upper-wind soundings commenced there only in 1962. However, another station—Mombasa (04°02′S, 39°37′E, 57 m)—lies close to the position where the core of

the current first comes inland from the Indian Ocean, and the length of record of upper winds is much greater. Also, the sounding program at Mombasa has been much more regular than at Garissa. For these reasons Mombasa was selected as the monitor station for this study. The mean characteristics of the low-level flow at these two stations is shown in Figure 2 where the mean southerly and easterly components of the July winds, up to the 3 km level, illustrate the jet-like profile of the southerly wind. The peak value at Garissa is higher because that station lies a little nearer to the core than Mombasa.

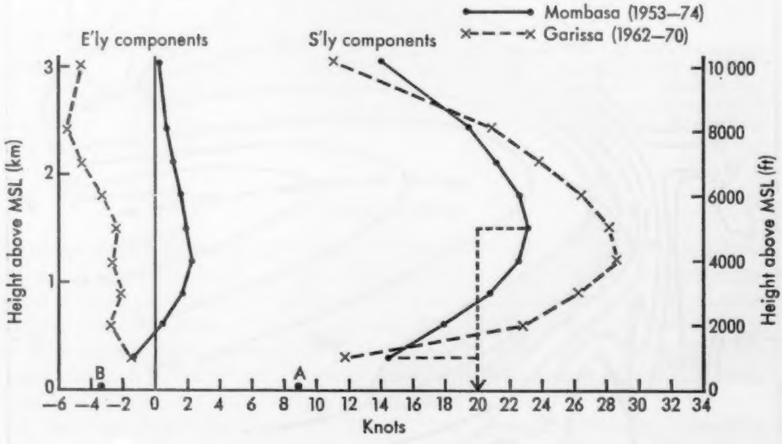

FIGURE 2—MEAN COMPONENTS OF THE LOW-LEVEL CURRENT IN JULY AT MOMBASA AND GARISSA

The index of cross-equatorial flow is the mean of the monthly values of the southerly component at 1000, 2000, 3000, 4000 and 5000 ft above MSL.

For Mombasa the 22-year mean of the index is 20·0 kn.

Points A and B represent the components of the mean daily surface wind in July at Mombasa, as calculated from data given by Ramsey (1971).

When monitoring the flow each July only the lower half of the profile shown in Figure 2 is used because many more pilot balloons reach the 1·5 km level than the 3 km level. The monitor value is calculated for each July as the mean of the southerly components of the wind at the levels of 0·3, 0·6, 0·9, 1·2 and 1·5 km above MSL (corresponding to winds measured at 1000, 2000, 3000, 4000 and 5000 ft above MSL). The 22-year mean of the monitor value for Mombasa for the years 1953 to 1974 is 20·0 kn (=10·3 m/s) and it is shown graphically in Figure 2. The monitor values for July in each of the years 1953–76 are listed in Appendix I*. Extreme values of 16·9 and 22·6 kn have been recorded. The monitor value for each year, hereinafter referred to as the wind index, is also shown in (a) of Figure 3.

***Pilot-balloon winds have been measured at Mombasa since 1937 but all daily records prior to 1953 have been destroyed. Only an incomplete set of monthly frequency tables for a few upper levels remains.**

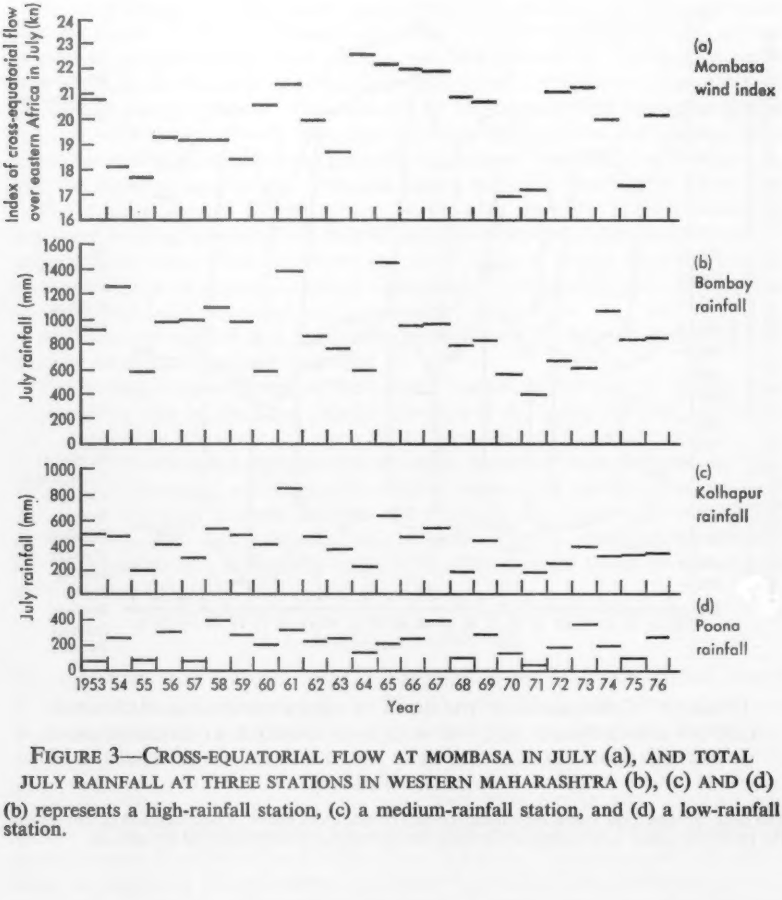

FIGURE 3—CROSS-EQUATORIAL FLOW AT MOMBASA IN JULY (a), AND TOTAL JULY RAINFALL AT THREE STATIONS IN WESTERN MAHARASHTRA (b), (c) AND (d)

(b) represents a high-rainfall station, (c) a medium-rainfall station, and (d) a low-rainfall station.

3. COMPARISON OF LOW-LEVEL FLOW OVER EASTERN KENYA AND THE RAINFALL OF WESTERN INDIA

The July rainfall of western India varies considerably from year to year and (b), (c) and (d) of Figure 3 show the total July rainfall at three stations in the western part of the State of Maharashtra, India for the years 1953–76. The three stations represent a high-rainfall station (Bombay), a medium-rainfall station (Kolhapur) and a low-rainfall station (Poona). The 1953–76 mean July rainfall values at these stations are 873·0, 390·0 and 208·2 mm respectively. Although these stations are at different altitudes and have different exposures, it is clear that all lie in the same rainfall regime. Wet and dry years are generally reflected at all three stations.

Data from these three stations can be combined for comparison with the Mombasa wind index. This comparison is shown in Figure 4. The profiles of

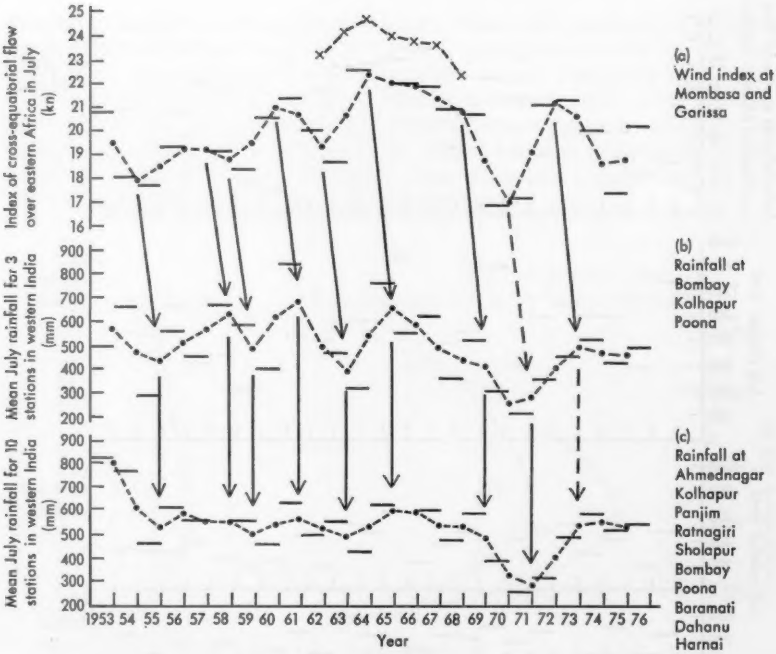

FIGURE 4—COMPARISON OF THE INDEX OF CROSS-EQUATORIAL FLOW OVER EASTERN AFRICA IN JULY (a), THE MEAN JULY RAINFALL AT THREE STATIONS IN WESTERN INDIA (b), AND THE MEAN JULY RAINFALL AT TEN STATIONS IN WESTERN INDIA (c)

The dots represent the mean July value for two consecutive years. The crosses in (a) represent the two-year mean July values at Garissa, for comparison with those of Mombasa.

the wind index, (a) of Figure 4, and of the mean rainfall at the three stations in India, (b) of Figure 4, show some similarities and also some differences. To assist interpretation, two-year overlapping mean values have been calculated. These values, plotted as dots joined by broken lines, illustrate a close association between the two derived parameters. Generally, peaks and troughs are nearly coincident but the striking feature is the lag between the two curves of overlapped mean values. Peaks and troughs in the rainfall lag behind, by one year, the corresponding features of the wind-index curve.

The physical causes of the lag are not yet known but it is hypothesized that the strength of the wind index influences the ocean currents and surface temperatures of the Arabian Sea in such a way that sea-surface temperature anomalies persist for one year, thus affecting the stability of the air, evaporation from the sea surface, and hence the rain-bearing potential of the Indian summer monsoon air. This hypothesis requires verification.

In (a) of Figure 4 crosses have been inserted to represent the two-year overlapping means of the wind index at Garissa in order to illustrate the correspondence between upper-wind stations near the core of the low-level current. The averages for Garissa have not been calculated for the years after 1968–69 because of paucity of data. For example, in 1970 upper-wind measurements at Garissa were made on only nine days in July. Nevertheless the Garissa wind index for earlier years shows the generally higher speeds recorded at that station, and the curve of the two-year averages shows the same trends as at Mombasa.

The comparison of the Mombasa wind index and the Indian rainfall is extended by using a total of ten rainfall stations in western Maharashtra instead of only three; these data are shown in (c) of Figure 4. Again the same general correspondence of curves is evident, though less pronounced, and the one-year lag is seen in both smoothed and unsmoothed values.

All wind and rainfall data used in these analyses are tabulated in Appendix I. Station details are listed in Appendix IV.

The correspondence between the rainfall curves of (b) and (c) of Figure 4 is not solely due to the three rainfall stations of (b) being included in the ten stations used to construct (c), since all stations used in this study show similar features in their rainfall regimes. For example, if another three stations, Dahanu, Harnai and Ratnagiri, are analysed in similar fashion, the pattern is the same and the lag of one year between troughs and ridges in the wind index and rainfall curves is repeated. It should be noted, however, that the relationships reported in this paper do not necessarily apply to rainfall stations which lie outside the area selected for study, or to other months.

4. Rainfall prediction

The lag of one year between significant features of the wind and rainfall, shown in Figure 4, suggests that the curve of Indian rainfall may be extrapolated one year ahead for the month of July only. The trend or change of the two-year mean values of the wind index may be determined and related to the trend of the two-year mean rainfall of western India one year later; for example, the change in the two-year mean wind index between 1953–54 and 1954–55 is −1·6 kn, and is related to the change in the two-year mean rainfall for the ten stations in western India for 1954–55 and 1955–56, −79·2 mm. These comparative values, listed in Appendix III and plotted in Figure 5, are calculated from data given in Appendix I. The line of best fit in Figure 5 is inserted by the method of least squares, whilst parallel and equidistant lines contain the range of observations. The correlation coefficient between the two-year wind-index change and the two-year mean rainfall change one year later is +0·82. Values for the correlation coefficient (r) for a lag varying from −2 to +2 years are:

Lag (years)	−2	−1	0	+1	+2
r	−0·43	−0·54	+0·41	+0·82	+0·04.

Provided that the trends of wind and rainfall over the last 24 years are preserved in future years, and provided that the pilot-balloon data at Mombasa remain sufficiently regular to furnish an accurate measure of the vigour of the cross-equatorial current (and bearing in mind the inherent uncertainty of extrapolating time-series into the future), then the type of diagram shown in Figure 5 might be used for experimental predictions of the July rainfall of western Maharashtra for one year ahead.

For example, the 1974–75 and 1975–76 mean values of the Mombasa wind index are 18·7 and 18·8 kn respectively, a change of +0·1 kn. From Figure 5 a change of +0·1 kn corresponds to a change of +2·0 mm (±80 mm) between the 1975–76 and 1976–77 mean July rainfall for the ten selected stations in western India. Because the 1975–76 mean rainfall is known to be 535·4 mm, the 1976–77 mean value may be predicted to be 535·4 + 2·0 = 537·4 mm (±80 mm).

Furthermore, the 1976 measured value of the rainfall is 551·1 mm and the predicted mean for 1976–77 is 537·4 mm, therefore the predicted mean for July 1977 is:

$$537{\cdot}4-(551{\cdot}1-537{\cdot}4) = 523{\cdot}7 \text{ mm } (\pm 160 \text{ mm}).$$

This predicted amount represents 97 per cent (±29·6 per cent) of the 24-year average July rainfall (540·1 mm) for the ten stations in western Maharashtra. The calculation of the forecast value may also be made graphically by using Figure 5 and (c) of Figure 4.

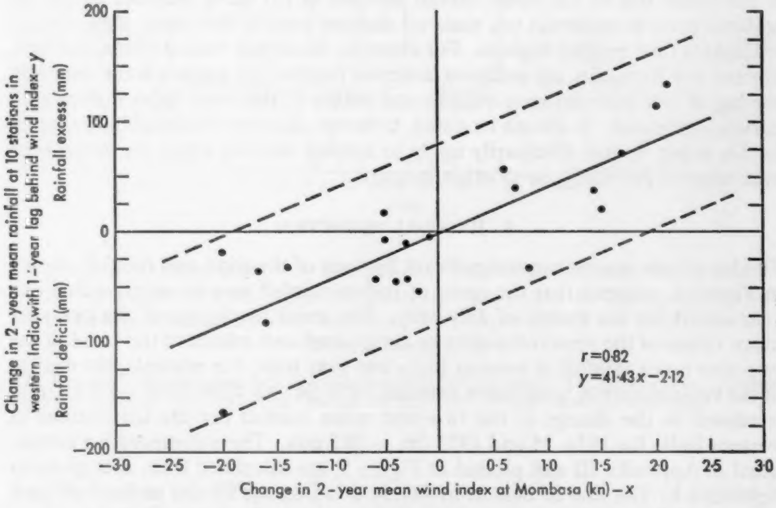

FIGURE 5—CHANGE IN TWO-YEAR MEAN CROSS-EQUATORIAL FLOW OVER EASTERN AFRICA RELATED TO THE CHANGE IN TWO-YEAR MEAN RAINFALL AT TEN STATIONS IN WESTERN INDIA ONE YEAR LATER

If similar calculations are made for all years for which data are available, as in Appendix II, it is evident that the mean July rainfall of the ten selected stations might have been forecast one year ahead with an average error of only 11·3 per cent, had the relationships between the Kenya wind index and the Indian rainfall then been known. The maximum error in the forecasts would have been 29·6 per cent. All details are listed in Appendix II.

Experimental forecasts using this method were made in August of 1972, 1973, 1974 and 1975 for the July rainfall of 1973, 1974, 1975 and 1976 respectively,

but data from these years have now been incorporated into the dependent data set and the correlation coefficient and line of best fit have been recalculated to the values now shown. However, it will be many years before the forecasting potential of this method can be adequately tested against an independent data set.

It is not the intention here to propose an operational forecasting technique as such, but rather to demonstrate that careful monitoring of the flow near the core of the cross-equatorial current over eastern Africa and the rainfall downstream over India may yield, after much further study, some relationships which might be useful in forecasting the rainfall of the Indian summer monsoon. This paper is only a short step in that direction.

5. Conclusions

Earlier work relating cross-equatorial flow at low levels over Kenya to the rainfall of western India, using five-day overlapping mean values during the northern summer, indicated that surges and lulls in the cross-equatorial flow were reflected in the rainfall of western India a few days later. This present study attempts to ascribe an index to the core of the cross-equatorial current in July for as many years as possible, so that the vigour of the monsoon current may be compared between years.

This index has been found to vary as the mean July rainfall of western Maharashtra, especially when two-year averages are used.

A feature of considerable interest is that there is a lag of one year in maxima and minima of rainfall behind those of the wind index. This lag may have some long-range predictive value.

Acknowledgements

The assistance of the Directors-General of the India Meteorological Department and the East African Meteorological Department in supplying the rainfall and wind data respectively is acknowledged with thanks.

The author is indebted to his colleagues Dr R. C. Hills and Mr K. J. Macleod for their critical examination of this paper and for the resulting amendments which have been introduced.

This paper is published with the permission of the Director-General of the East African Meteorological Department.

References

FINDLATER, J. 1966 Cross-equatorial jet streams at low level over Kenya. *Met Mag*, **95**, pp. 353–364.

1967 Some further evidence of cross-equatorial jet streams at low level over Kenya. *Met Mag*, **96**, pp. 216–219.

1969a A major low-level air current near the Indian Ocean during the northern summer. *Q J R Met Soc*, **95**, pp. 362–380.

1969b Interhemispheric transport of air in the lower troposphere over the western Indian Ocean. *Q J R Met Soc*, **95**, pp. 400–403.

1971 Mean monthly airflow at low levels over the western Indian Ocean. *Geophys Mem*, **16**, No. 115.

RAMSEY, B. 1971 Surface winds at Mombasa, Kenya. *Met Mag*, **100**, pp. 293–301.

APPENDIX I—MEAN WIND INDEX AT MOMBASA, KENYA, AND MEAN RAINFALL AT STATIONS IN WESTERN INDIA: JULY ONLY

	Wind index		Rainfall													
	Mombasa	Overlapped mean	Ahmednagar	Baramati	Dahanu	Harnai	Kolhapur	Panjim	Ratnagiri	Sholapur	Bombay (Santa Cruz)	Poona	Mean of Bombay, Kolhapur, Poona	Overlapped mean	Mean of all stations	Overlapped mean
	knots							*millimetres*								
1953	20·8	19·5	136·9	*	837·9	1502·1	484·3	1720·8	1545·3	278·8	922·0	68·6	491·6	576·7	832·9	800·9
1954	18·1	17·9	129·2	117·6	1070·3	1294·6	474·2	1404·8	1501·1	185·9	1264·9	246·4	661·8	472·6	768·9	613·0
1955	17·7	18·5	59·4	62·9	352·2	958·5	192·5	1077·9	1067·0	144·2	586·7	71·1	283·4	422·1	457·2	533·8
1956	19·3	19·3	149·8	89·9	1397·0	571·7	399·7	1064·2	842·7	306·5	983·0	299·7	560·8	506·1	610·4	587·4
1957	19·2	19·2	77·7	27·9	966·7	1117·0	284·9	922·0	1046·9	133·0	993·1	76·2	451·4	561·3	564·5	557·5
1958	19·2	18·8	137·4	65·2	995·2	740·8	519·4	780·4	689·7	83·6	1097·1	397·3	671·3	628·1	550·6	552·8
1959	18·4	19·5	58·3	38·0	1365·6	535·4	484·6	1086·4	590·6	122·0	987·5	282·6	584·9	490·9	555·1	505·3
1960	20·6	21·0	73·4	15·1	629·3	882·9	402·3	825·8	850·0	88·4	589·8	198·2	396·8	622·9	455·5	543·4
1961	21·4	20·7	72·4	35·4	1240·7	797·3	844·3	*	856·2	133·8	1385·5	316·9	848·9	683·5	631·3	564·6
1962	20·0	19·3	33·7	40·6	1031·6	833·6	472·0	*	820·0	168·5	858·3	224·1	518·1	488·7	498·0	524·5
1963	18·7	20·7	110·1	51·5	1177·1	1094·7	365·4	*	1052·2	97·2	760·0	252·1	459·2	387·7	551·1	493·7
1964	22·6	22·4	112·0	54·5	728·1	690·2	225·2	841·4	778·0	210·2	588·3	137·1	316·2	538·8	436·3	530·2
1965	22·2	22·1	126·9	39·0	979·3	758·9	624·9	997·5	907·7	148·1	1455·5	203·8	761·4	654·9	624·2	600·7
1966	22·0	21·9	82·0	84·2	746·7	932·0	458·9	979·4	1137·1	166·6	944·0	241·9	548·3	586·8	577·3	591·4
1967	21·9	21·4	164·5	77·2	714·1	814·8	534·5	1104·0	1029·1	276·8	962·2	379·2	625·3	490·3	605·6	539·9
1968	20·9	20·8	120·9	79·6	533·8	804·5	182·7	1334·7	710·6	91·8	793·9	89·2	355·3	433·9	474·2	533·6
1969	20·7	18·8	180·7	132·8	416·8	1204·3	432·3	843·5	1417·7	197·3	828·8	276·2	512·4	408·1	593·0	492·1
1970	16·9	17·1	45·0	6·9	567·8	549·9	229·5	830·7	850·8	149·8	549·0	132·9	303·8	252·3	391·2	327·1
1971	17·2	19·1	4·3	0·0	358·6	432·4	174·6	760·7	447·7	24·4	384·9	42·6	200·7	277·5	263·0	291·7
1972	21·1	21·2	12·8	2·3	345·8	672·6	241·6	594·0	489·8	24·6	651·2	169·7	354·2	401·1	320·4	403·7

1973	21·3		80·5	117·3	766·4	731·9	385·5	814·7	887·0	128·4	608·4	350·2	448·0		487·0	
1974	20·0	20·7	55·9	32·8	989·2	956·2	306·6	1018·7	1160·8	84·3	1066·3	180·0	517·6	482·8	585·0	536·0
1975	17·4	18·7	202·4	43·4	382·4	845·5	317·6	1206·2	1045·3	223·2	835·5	95·9	416·3	466·9	519·7	552·3
1976	20·2	18·8	45·8	39·4	826·1	915·5	323·5	1065·0	1081·2	93·7	855·7	265·5	481·6	448·9	551·1	535·4
Mean	19·9		94·7	54·5	809·1	859·9	390·0	1013·0	950·2	148·4	873·0	208·2			540·1	

* Data not available

APPENDIX II—TEST OF THE FORECASTING TECHNIQUE USING DEPENDENT DATA AND THE DERIVED RELATIONSHIP,

$y = 41{\cdot}43x - 2{\cdot}12$: JULY ONLY

Change in 2-year mean wind index x		Forecast change in 2-year mean rainfall y		Actua lmean 2-year rainfall a		Forecast mean 2-year rainfall $b = a + y$		Actual rainfall c		Forecast rainfall $c + 2(b-c)$		Actual rainfall		Error	Rainfall, percent. of normal		Error
Years	*knots*	*Years*	*mm*	*Years*	*mm*	*Years*	*mm*	*Year*	*mm*	*Year*	*mm*	*Year*	*mm*	*mm*	F'cast %	Actual %	%
53/54—54/55	−1·6	54/55—55/56	−67·9	54/55	613·0	55/56	545·1	55	457·2	56	633·0	56	610·4	+22·6	117·2	113·0	+4·2
54/55—55/56	+0·6	55/56—56/57	+22·7	55/56	533·8	56/57	556·5	56	610·4	57	502·6	57	564·5	−61·9	93·1	104·5	−11·4
55/56—56/57	+0·8	56/57—57/58	+31·0	56/57	587·4	57/58	618·4	57	564·5	58	672·3	58	550·6	+121·7	124·5	101·9	+22·6
56/57—57/58	−0·1	57/58—58/59	−6·3	57/58	557·5	58/59	551·2	58	550·6	59	551·8	59	555·1	−3·3	102·2	102·8	−0·6
57/58—58/59	−0·4	58/59—59/60	−18·7	58/59	552·8	59/60	534·1	59	555·1	60	513·1	60	455·5	+57·6	95·0	84·3	+10·7
58/59—59/60	+0·7	59/60—60/61	+26·9	59/60	505·3	60/61	532·2	60	455·5	61	608·9	61	631·3	−22·4	112·7	116·9	−4·2
59/60—60/61	+1·5	60/61—61/62	+60·0	60/61	543·4	61/62	603·4	61	631·3	62	575·5	62	498·0	+77·5	106·5	92·2	+14·3
60/61—61/62	−0·3	61/62—62/63	−14·5	61/62	564·6	62/63	550·1	62	498·0	63	602·2	63	551·1	+51·1	111·5	102·0	+9·5
61/62—62/63	−1·4	62/63—63/64	−60·1	62/63	524·5	63/64	464·4	63	551·1	64	377·7	64	436·3	−58·6	69·9	80·8	−10·9
62/63—63/64	+1·4	63/64—64/65	+55·9	63/64	493·7	64/65	549·6	64	436·3	65	662·9	65	624·2	+38·7	122·7	115·6	+7·1
63/64—64/65	+1·7	64/65—65/66	+68·3	64/65	530·2	65/66	598·5	65	624·2	66	572·8	66	577·3	−4·5	106·1	106·9	−0·8
64/65—65/66	−0·3	65/66 66/67	−14·5	65/66	600·7	66/67	586·2	66	577·3	67	595·1	67	605·6	−10·5	110·2	112·1	−1·9
65/66 66/67	−0·2	66/67—67/68	−10·4	66/67	591·4	67/68	581·0	67	605·6	68	556·4	68	474·2	+82·2	103·0	87·8	+15·2
66/67—67/68	−0·5	67/68—68/69	−22·8	67/68	539·9	68/69	517·1	68	474·2	69	560·0	69	593·0	−33·0	103·7	109·8	−6·1
67/68—68/69	−0·6	68/69—69/70	−27·0	68/69	533·6	69/70	506·6	69	593·0	70	420·2	70	391·2	+29·0	77·8	72·4	+5·4
68/69—69/70	−2·0	69/70—70/71	−85·0	69/70	492·1	70/71	407·1	70	391·2	71	423·0	71	263·0	+160·0	78·3	48·7	+29·6
69/70—70/71	−1·7	70/71—71/72	−72·5	70/71	327·1	71/72	254·6	71	263·0	72	246·2	72	320·4	−74·2	45·6	59·3	−13·7
70/71—71/72	+2·0	71/72—72/73	+80·7	71/72	291·7	72/73	372·4	72	320·4	73	424·4	73	487·0	−62·6	78·6	90·2	−11·6
71/72—72/73	+2·1	72/73—73/74	+84·9	72/73	403·7	73/74	488·6	73	487·0	74	490·2	74	585·0	−94·8	90·8	108·3	−17·5
72/73—73/74	−0·5	73/74—74/75	−22·8	73/74	536·0	74/75	513·2	74	585·0	75	441·4	75	519·7	−78·3	81·7	96·2	−14·5
73/74—74/75	−2·0	74/75—75/76	−85·0	74/75	552·3	75/76	467·3	75	519·7	76	414·9	76	551·1	−136·2	76·8	102·0	−25·2
74/75—75/76	+0·1	75/76—76/77	+2·0	75/76	535·4	76/77	537·4	76	551·1	77	523·7	77	—	—	97·0	—	—

Average error = 61·0 mm 11·3 %

= 11·3 per cent of the 24-year average July rainfall for the 10 stations in western India (540·1 mm).

APPENDIX III—CHANGE IN 2-YEAR MEAN WIND INDEX RELATED TO CHANGE IN 2-YEAR MEAN RAINFALL ONE YEAR LATER

Change in 2-year mean wind index at Mombasa, Kenya	*knots*	Change in 2-year mean rainfall at ten selected stations in western India, one year later	*mm*
1953/54—1954/55	−1·6	1954/55—1955/56	−79·2
1954/55—1955/56	+0·6	1955/56—1956/57	+53·6
1955/56—1956/57	+0·8	1956/57—1957/58	−29·9
1956/57—1957/58	−0·1	1957/58—1958/59	−4·7
1957/58—1958/59	−0·4	1958/59—1959/60	−47·5
1958/59—1959/60	+0·7	1959/60—1960/61	+38·1
1959/60—1960/61	+1·5	1960/61—1961/62	+21·2
1960/61—1961/62	−0·3	1961/62—1962/63	−40·1
1961/62—1962/63	−1·4	1962/63—1963/64	−30·8
1962/63—1963/64	+1·4	1963/64—1964/65	+36·5
1963/64—1964/65	+1·7	1964/65—1965/66	+70·5
1964/65—1965/66	−0·3	1965/66—1966/67	−9·3
1965/66—1966/67	−0·2	1966/67—1967/68	−51·5
1966/67—1967/68	−0·5	1967/68—1968/69	−6·3
1967/68—1968/69	−0·6	1968/69—1969/70	−41·5
1968/69—1969/70	−2·0	1969/70—1970/71	−165·0
1969/70—1970/71	−1·7	1970/71—1971/72	−35·4
1970/71—1971/72	+2·0	1971/72—1972/73	+112·0
1971/72—1972/73	+2·1	1972/73—1973/74	+132·3
1972/73—1973/74	−0·5	1973/74—1974/75	+16·3
1973/74—1974/75	−2·0	1974/75—1975/76	−16·9
1974/75—1975/76	+0·1	1975/76—1976/77	?

Correlation coefficient (r) = +0·82 (significant at the 1 per cent level of probability).

APPENDIX IV—LIST OF STATIONS USED IN THE ANALYSIS

For wind analysis

Station No.	Station	Position	Height above MSL *metres*
63723	Garissa	00°29′S 39°38′E	128
63820	Mombasa	04°02′S 39°37′E	57

For rainfall analysis

Station No.	Station	Position	Height above MSL *metres*
43009	Ahmednagar	19°05′N 74°48′E	657
43069	Baramati	18°09′N 74°35′E	551
43001	Dahanu	19°58′N 72°43′E	5
43109	Harnai	17°49′N 73°06′E	20
43157	Kolhapur	16°42′N 74°14′E	570
43192	Panjim	15°29′N 73°49′E	57
43110	Ratnagiri	16°59′N 73°20′E	35
43117	Sholapur	17°40′N 75°54′E	479
43003	Bombay (Santa Cruz)	19°07′N 72°51′E	14
43063	Poona	18°32′N 73°51′E	559

551.593.653

NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND THE ATLANTIC DURING 1976

By D. H. McINTOSH and MARY HALLISSEY
(Department of Meteorology, University of Edinburgh)

Table I summarizes the observations of noctilucent clouds (NLC) made over western Europe and the Atlantic during 1976 and reported to the Department of Meteorology, Edinburgh University.

Observers' reports, positive or otherwise, were requested for the months May to August. As in previous years, sightings were confined to the period from late May to early August. The periods of time during which the clouds were observed appear in the second column of the Table. These should not be taken as being necessarily the total duration of the display; this is stated where possible, but it is obviously difficult, particularly for voluntary observers, to record a display to the point of disappearance. Brief notes on the displays appear in the third column. In the remaining columns, details of the relevant station co-ordinates are listed to the nearest half degree, and the maximum elevation and limiting azimuths of the observed cloud, where known.

Positive reports were received from some 30 stations of the Meteorological Office station network of Great Britain and of the Meteorological Service of Ireland, ranging from Lerwick to Mount Batten, Plymouth, and from Birr to Wattisham; also from a Fair Isle lighthouse-keeper and from 10 voluntary observers scattered throughout the UK, Denmark and Norway. We are grateful to Drs Gadsden and Jenkins of Aberdeen University for observations recorded in their log in connection with their work for the International Magnetospheric Study on the polarization of NLC.

Records of tropospheric cloud amounts were also received from Meteorological Office stations, including nights on which no positive observations of NLC were made. The confirmed absence of NLC, especially during what is statistically their peak incidence time (mid-June to mid-July) is now regarded as significant 'negative' information. Unfortunately, the incidence of tropospheric cloud and haze was rather high during this four week period and no negative finding can be regarded as definitely confirmed.

Time-lapse photography of the clouds was carried out on most nights from Edinburgh and revealed one occasion, in particular, on which there was a dramatic invasion of the sky, by movement of the clouds from the north, late in the night.

A special study of the display of 18–19 June was made by an observer, Dr D. A. R. Simmons of Milngavie, near Glasgow, whose paper on the event has been accepted for publication in *Weather*.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND THE ATLANTIC DURING 1976

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev. *degrees*	Limiting azimuths *degrees*
27/28 May	0130	Patch of NLC seen from train when observer travelling NE England	54·5N 01·5°W	0130	5	

TABLE I—*continued*

Date—night of	Times UT	Notes	Station position*	Time UT	Max. elev. degrees	Limiting azimuths degrees
2/3 June	2210–0200	Some doubt by observers in Aberdeen as to authenticity of NLC to high elevation before 2300 but NLC seen clearly from more southerly stations one of which later reported veil and billow formation. From northerly station NLC faint and diffuse without marked regular structure. At 0020 as seen from Aberdeen northern edge of cloud field clear of N horizon.	57°N 02°W	2220	50	045
				2315	5	340–045
				0020	10	045
			55·5°N 01·5°W	2330	7½	330–010
				0050	9	350–010
			55°N 04·5°W	2230	15	020
			54°N 04·5°W	2400	5	345–015
				0200	10	340–040
5/6	0115–0150	NLC already at max. when first seen at 0115: compact herring-bone-pattern patch with N edge 11° NNE–NE. Intensity, never high, faded progressively until dawn, around 0200.	56°N 04·5°W	0115	27	014–043
6/7	0001–0030	Fairly bright but featureless bands seen from southern position; later seen in breaks in tropospheric cloud from Edinburgh.	56°N 03°W	0030		
			51°N 02°W	0001	7	340–015
7/8	2110–0215	Bright NLC with fine herring-bone structure seen from Denmark (photographs available): marked longitudinal extension to east; from Liverpool seen as veil background to brighter bands, fading into haze.	56°N 03°W	2240	10	310–360
			55·5°N 12°E	2200		
			55°N 14·5°E	2110	40	270–020
				2245	18	315–070
				2328	11	315–070
			53·5°N 03°W	0110	5	020–040
				0200	3	020–040
8/9	2200, 2230	NLC visible through breaks in tropospheric clouds in Denmark; herring-bone pattern discernible Edinburgh.	56°N 03°W	2230	30	
			55·5°N 12°E			
9/10	2400, 0200	Details obscured by cloud from Ronaldsway; banded structure discernible from Watnall.	54°N 04·5°W			340–020
			53°N 01·5°W	0200	10	340
10/11	2330	Moderately bright NLC above cloud bank to 5°. Fairly extensive cloud field, but E limit hidden by tropospheric clouds.	56°N 03°W	2330	12	
17/18 June	0045–0200+	Very bright bands and billows with veil background became visible after midnight from Newcastle. Earlier in Denmark, NLC recognized in tropospheric cloud breaks.	55°N 14·5°E	2150	5	360
			55°N 01·5°W	0045	10	340–020
				0145	15	350–030
18/19	2340–0300	Earliest sighting of bright bands from Ronaldsway, I.O.M. Max. extension southwards around 0200 when southern edge of cloud field, though obscured by tropospheric clouds at many stations, was overhead at Boulmer, Northumbria, and to elevation of 160° from Aberdeen. NLC structure described variously as 'tangled', 'feathery'. Measurements made from series of photographs taken near Glasgow.	57·5°N 03·5°W	2400	21	340–020
			57°N 02°W	2345	22	340–020
				0030	28	315–020
				0200	160	135
			56·5°N 03°W	2400	20	340–010
			56°N 04·5°W	0030	25	340–040
				0130	25	330–040
			56°N 03°W	2345	15	340
			55·5°N 01·5°W	0100	15	330–030
				0200	85	330–070
			54·5°N 06°W	0115		340–080
				0200		330–110
			54°N 04·5°W	2340	10	320–023
				0040	12	320–040
				0200	20+	320–090+
19/20	2330–2350	Short-lived period of visibility before NLC obscured by tropospheric cloud.	55·5°N 05°W	2330	10	315
21/22	2300	In UK brief recognition through tropospheric cloud break—no identification of form. Bright display seen Denmark above tropospheric cloud to 10°.	57°N 02°W	2300	45	045
			56°N 03°W	2308		
			55·5°N 12°E	2200	25	340–045
			53°N 01·5°W	2300		360
22/23	0030	In Edinburgh NLC glow visible through tropospheric cloud covering N sky to zenith.	56°N 03°W	0030		
	0518–0553	NLC visible from aircraft over Newfoundland.	48°N 55°W	0530		
23/24	2315	NLC visible through breaks in tropospheric cloud.	56°N 03°W			

* To nearest 0·5 degree.

TABLE I—*continued*

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev. (degrees)	Limiting azimuths (degrees)
24/25	2310	Faint NLC above cloud bank to 10°.	56°N 03°W	2310	20	360
26/27	2400–0200	Veil with band formation visible from all reporting stations (including the top of Ben Lomond). Extensive sighting and detailed report from Aldergrove; there, as earlier in Denmark, bands, billows and whirl formations identified, the tenuous structure thickening into broad bands at southern edge before fading in brightening sky. 4° elevation of northern edge as seen from Aldergrove.	56°N 04·5°W	2400	15	345–015
			56°N 03°W	2315	15+	
			55·5°N 07·5°W	2400	11	360–040
				0200	21	355–060
			55·5°N 01·5°W	0100	13	022–045
			55·5°N 12°E	0030		360–045
			55°N 14·5°E	2100	25	360–045
				2120	30	340–045
				2140	30	340–045
			55°N 04·5°W	0110		
			54·5°N 06°W	2400	12	350–040
				0100	17	350–045
				0130	20	350–050
			54°N 04·5°W	0100	5	345–015
			53°N 01·5°W	0100	6	360–020
				0200	12	340–030
27/28	2234–0200	Steady, slow-moving display seen Ireland and I.O.M., mainly in NW sky, and in tropospheric cloud breaks Edinburgh. Weak veil and brighter bands, with whirl formation suspected around 2300.	56°N 03°W	2310		330
			54·5°N 06°W	2300	14	290–020
				0100	7	340–360
			54°N 04·5°W	2250	11	300–355
				2350	12	325–020
			53·5°N 07·5°W	2300	11	310–015
				0100	7	340–040
				0200	8	350–020
28/29	2250, 0100	Faint patches of NLC in clear sky seen from NE England, and above haze layer (to 5°) from Edinburgh.	56°N 03°W	2250	5+	360
			55·5°N 01·5°W	0100	9	340–040
29/30	2345–0245	NLC visible to low latitudes over UK—seen first from Norfolk just above and parallel to N horizon; developed to herring-bone formation. Stacking of S-shaped bands seen Northolt 0140. NLC visible very brightly 0145–0245 from Plymouth. Intense glow in NNE reduced to bright fibrous strands as sun rose. Southerly stations reported orange tinge at N edge of cloud field. Maximum extension around 0200.	54·5°N 06°W	0200	14	340–030
			53°N 08°W	0200	20	360–030
			52·5°N 0·5°E	0005	2	010
				0145	5	310–020
			52°N 01°E	0020	4	360
				0200	16	330–010
				0225	12	310–360
			51·5°N 02°W	0200	10	340–020
			51·5°N 0·5°W	0045	4	347–352
				0100	5	340–025
				0125	8	330–030
				0200	10	320–020
			51°N 01·5°W	0200	4	016
			50·5°N 3·5°W	0151	10	340–010
			50·5°N 05°W	0145	17	350–070
				0245	12	350–070
30 June/1 July	2300–0220	Display visible only in northern and central Ireland, possibly due to haze interference in many areas. When clear of haze, NLC forms very bright, e.g. around 0200 as seen Aldergrove.	55·5°N 07·5°W	0030	11	350–360
			54·5°N 06°W	0200	9	350–080
				0220	12	
			53°N 08°W	2300	20	330–360
1/2	2250–2400	In Aberdeen two observers, independently, suspected presence of NLC visible through haze at high elevation.	57°N 02°W	2310	70	360–090
5/6	2200–2230	NLC visible Denmark with gradually increasing brightness.	55·5°N 12°E	2200		315
6/7	2320–0300	Prolonged, extensive and bright display of NLC widely reported Scotland, N and central England, though seen dimly through haze in some areas. N–S direction of bands with fibrous cross structure. At 0200 bright band stretched almost to zenith over Leuchars, and at Boulmer 0220–0230 NLC reached high elevation to east and west of station. Whirl formation reported at 0145–0215. Elevation of N edge unreliable due to haze.	57·5°N 03·5°W	0100		
			57°N 02°W	2340	9	340
			56·5°N 03°W	2330	15	310–030
				0030	14	335–015
				0115	17	320–025
				0200	56	320–025
			56°N 03°W		15	
			55·5°N 01·5°W	0145	22½	340–050
				0210	25	360
				0220	45	330
				0230	25	360
			53°N 0·5°W	0200	13	340–060
/10 July	2315	Band of NLC visible NW–NE from Edinburgh.	56°N 03°W	2315	7	345–045
1/12	2100–2220	NLC seen, as soon as sky darkened, to occupy large area of twilit hemisphere—to zenith as seen from W. Yorks. and Berkshire—until obscured by moonlit tropospheric clouds. NLC photographed 2210 W. Yorks.	54°N 02°W	2150	80	
				2203	45	265–030
				2220	20	290–360
			53°N 0·5°W	2200	12	345–360
			51·5°N 0·5°W	2200	65	345–360

TABLE I—*continued*

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev. (degrees)	Limiting azimuths (degrees)
12/13	2250	NLC visible through breaks in tropospheric cloud (to 13°).	56°N 03°W	2250	13+	045
15/16	2330 0050–0215	Low elevation NLC seen after clearing of tropospheric cloud; thin delicate structure.	57·5°N 03·5°W	0100	12	340–015
			57°N 02°W	0100	12	340–010
			56°N 03°W	2320	10	340
			55·5°N 04·5°W	0145	4	340–010
			55°N 04·5°W	0150		
16/17	0200	Short-lived appearance of NLC in E in break in tropospheric cloud.	57·5°N 03·5°W	0200	10	080–090
18/19	0030	Compact formation NLC from NE horizon to 40° elevation seen Norway.	59°N 09°E	0030	40	045
20/21	2346–0220	Whirl formation seen from northerly stations; more general reporting of bright bands spreading to high elevation over N Scotland and visible from central England. NLC photographed Aberdeen 2353–0219. Observation from Denmark hampered by cloud and moonlight, but brightening NLC bands seen in cloud breaks.	57°N 02°W	2346		020
				0050		320–030
				0150		350–070
			56°N 03°W	0115		360, 020
			56°N 10°E	0005	10	045
				0055	12	340–060
			55·5°N 01·5°W	0100	7½	360–030
				0200	7½	360–030
			53°N 01·5°W	0200	4	020
21/22	2200, 0100	Possible display of NLC bands high in SE seen Norway; faint NLC suspected Edinburgh.	59°N 09°E			
			56°N 03°W	0100		020
24/25	2335–0100	In Denmark bands of NLC seen first through breaks in tropospheric cloud; varying brightness; photographed 0047.	56°N 10°E	2335	6	340–360
				0035	8	360
				0100	10	360
25/26	2135–0105	In Denmark first seen faintly in fine observing conditions to 12° but disappeared 2205. Visible again 2400 with finely striated structure fading later into light sky.	56°N 10°E	2135	12	315–360
				2400	5	315–360
				0030	7	315–360
31 July/1 Aug.	0040–0200	Very bright display of NLC with typical band and billow formation of degree of brightness and extent not previously seen by the observer at this time of year. Series of photographs.	56°N 10°E	0040	5	360–045
				0050	8	
				0113	10	
				0135		340–090
2/3 Aug.	2145 0145–0305+	Possible weak display of NLC reported at earlier time from Norway. From 0145 to about 0300 bright NLC bands visible from two of most northerly Met. stations and Fair Isle lighthouse to remarkably high elevation in conditions almost clear of tropospheric cloud.	60°N 01°W	0200	15	020–080
				0210	19	
				0230	23	
				0245	31	
			59°N 03°W	0145	8	010–040
				0230	12	010–045
				0250	14	020–050
			59°N 09°E	2145	90	360
19/20	0400	Suspected NLC	53°N 01·5°W	0400	22	070

551.577.37(41–4)

EVALUATING THE PROBABILITY OF HEAVY RAIN

By M. C. JACKSON

SUMMARY

Some of the weaknesses of the traditional Bilham methods for estimating rainfall depth, duration and return period are discussed. It is shown how much improved estimates for anywhere in the United Kingdom can be made using the methods described in Volume II of the *Flood Studies Report* (Meteorological Office, 1975).

The methods are based on maps of the 60-minute and 2-day rainfalls with return period 5 years. This paper describes how to obtain estimates of rainfall for the same return period for other durations using these two basic maps, and also how to extend rainfall estimates up to return periods of 1000 years. A method of estimating areal rainfall from the already derived point rainfalls is also described.

1. INTRODUCTION

Engineers concerned with urban drainage, sewerage, management of river catchments, planning construction, etc. have for many decades requested information about rainfall amount and return period for different parts of the country and for various durations and sizes of area. (A rainfall with return period T years is one that has a probability of $1/T$ of being equalled or exceeded in any one year.) In the past such enquiries have usually been answered by reference to the Bilham equation and tables, which gave the engineer an estimate of the probability of return period of a specified amount of rain falling in a specified duration. The equation was first presented in *British Rainfall* (Bilham, 1935).

However, the amount of data used by Bilham was limited to only 120 station years; other weaknesses are that only one equation was derived to represent the whole of the United Kingdom, and that durations were limited to two hours or less. Consequently estimates of rainfall with return period greater than 5 years were often in considerable error.

A modified Bilham equation (Holland, 1964) was more complex, adjusting the results when the intensity is greater than 1·25 inches per hour (32 millimetres per hour). However, no other changes were made to improve estimates of rainfall values with return periods greater than 5 years, and, in fact, further rainfall values for durations from 2 hours to 24 hours were obtained by simply extrapolating the Bilham equation beyond 2 hours.

Consequently there has been a need for many years both to collect many more data and to devise techniques for accurately estimating depth, duration and return period information for individual places in the United Kingdom.

In 1969 a major project, the United Kingdom Flood Studies, was established by the Natural Environment Research Council (NERC). The meteorological studies were directed by A. F. Jenkinson of the Meteorological Office, and one of the main products of the three years' work (1970–73) was Volume II (Meteorological Studies) of a comprehensive *Flood Studies Report* (Meteorological Office, 1975). For this work 3000 station years of data from autographic recording rain-gauges and 40 000 station years of daily rainfall data were collected and analysed. Most of the methods described by A. F. Jenkinson and M. C. Jackson in the *Flood Studies Report*, and by Jenkinson (1976), and described briefly in this paper, can be used to give estimates of rainfall and return period for different parts of the country and for various durations and various sizes of area.

More recently some of the calculations have been made by computer, and Keers and Westcott (1977) describe these computer programs.

2. Mapping the magnitude of rainfall events with return period 5 years

Key parameters were needed which could be mapped to give fundamental values on which to base estimates of rainfall amounts with long return periods (as well as being used to standardize the very large amounts of information obtained from the data). The key return period chosen was 5 years, and events for all durations with a return period of 5 years (sometimes called the M5) were linked together.

A return period of 5 years was chosen as a standard since it satisfies two basic requirements: (i) the larger the return period which is used as a standard, the better will be the estimation of events with even larger return periods, (ii) the smaller the return period, the better the chance of estimating its value accurately. The return periods satisfying (i) and (ii) are between 2 and 20 years, and 5 years was chosen for theoretical reasons. (The magnitude of the M5 rainfall event can be estimated by the reader by calculating the geometric mean of the top half of an ordered set of annual maxima—see *Flood Studies Report*, Volume II, Chapter 2.2.)

In order that M5 events can be estimated at any specific place for all durations, the magnitude of the M5 event for each of two durations at that place are calculated, and then, with a relationship derived from all the data, the magnitudes of the M5 event for all the other durations can be estimated (Section 3).

The two key durations chosen for M5 mapping were 60 minutes (Figure 1) and 2 rainfall days (Figure 2), after *Flood Studies Report*, Volume II, Figures 3.6* and 3.3 respectively. Sixty minutes is the shortest duration for which rainfall is usually tabulated One rainfall day (0900–0900 GMT) would seem the most logical duration for the second key event, with many cyclonic disturbances giving heavy rain which lasts for about a day. However, the rainfall event is often cut in two by an 0900 observation: this problem is overcome by choosing a duration of 2 rainfall days. The 2 rainfall-day event is smaller than the 48-hour event because a 48-hour event can commence at any hour of the day and continue for 48 hours, while the 2 rainfall-day event, although lasting for 48 hours, can only start at the 0900 morning observation. The ratio of the 48-hour event to the 2 rainfall-day event with the same return period is approximately 1·06—see *Flood Studies Report*, Volume II, Chapter 3.3.3. The same happens with rainfall data for 60 minutes compared with a clock hour and with data for 30 days compared with a calendar month.

3. Estimation of the magnitudes of rainfall events with return period 5 years for all durations at any place

Autographic rainfall data from recording rain-gauges in the United Kingdom were analysed extensively to give the table below. Given the values of the M5 rainfall for duration 60 minutes and 2 rainfall days, and the ratio of the two values, Table I allows estimates to be made for durations from 1 minute to 48 hours. Table I is based on *Flood Studies Report*, Volume II, Tables 3.6 and 3.7.

---

* The map originally published as 3.6 was inserted in error, and a corrigendum has been issued.

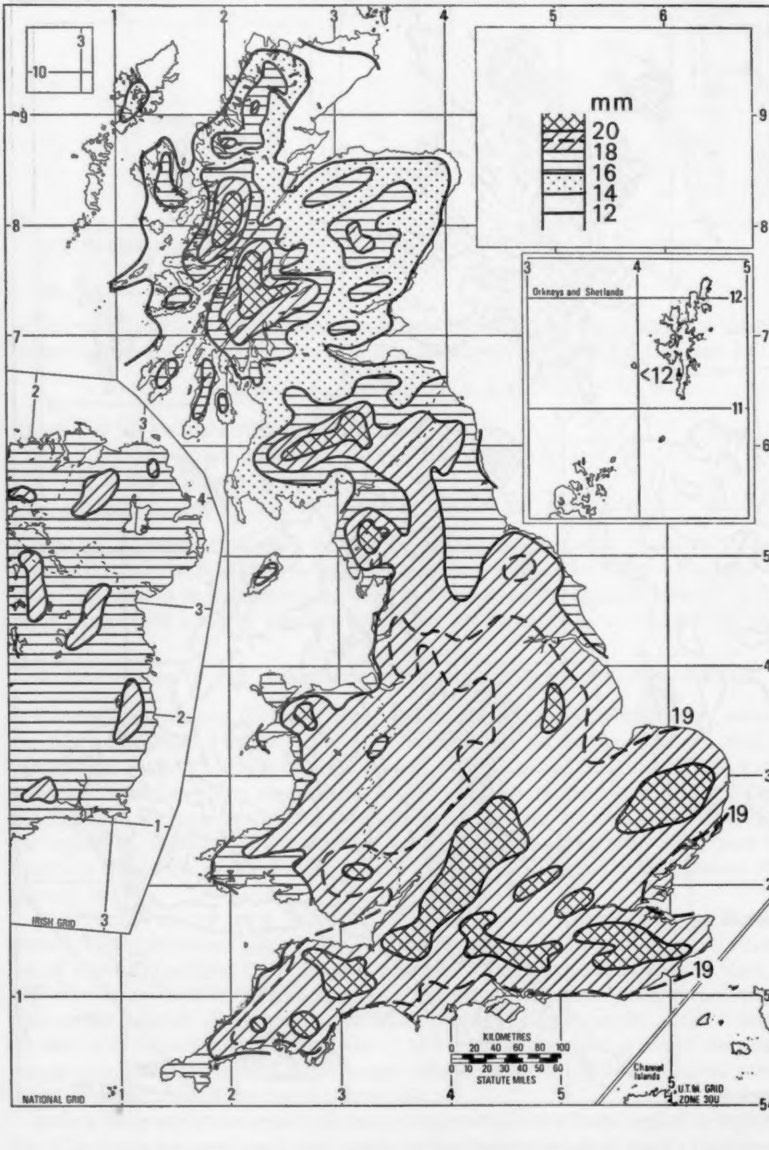

FIGURE 1—MAP OF RAINFALL AMOUNT FALLING IN 60 MINUTES WITH RETURN PERIOD 5 YEARS (M5)

FIGURE 2—MAP OF RAINFALL AMOUNT FALLING IN 2 RAINFALL DAYS WITH RETURN PERIOD 5 YEARS (M5)

TABLE I—METHOD OF ESTIMATING M5 RAINFALL FOR ALL DURATIONS

r	Duration (d) in minutes							Duration (D) in hours					
	1	2	5	10	15	30	120	2	4	6	12	24	48
				x							X		
0·44	12	21	38	54	64	83	120	53	63	68	79	92	106
0·39	11	20	36	52	62	81	123	47	57	63	75	89	106
0·32	11	19	35	50	60	79	126	40	50	56	70	86	106
0·26	11	18	33	47	57	76	130	34	43	50	65	83	106
0·22	10	17	31	45	54	74	134	29	39	46	61	80	106
0·17	9	15	27	41	50	71	139	24	33	40	55	77	106
0·12	7	12	23	35	45	67	149	18	26	33	49	72	106

r = ratio of M5 rainfall for 60 minutes to M5 rainfall for 2 days.
x = ratio (per cent) of M5 rainfall for d minutes to M5 rainfall for 60 minutes.
X = ratio (per cent) of M5 rainfall for D hours to M5 rainfall for 2 days.

The relationship of M5 rainfall with duration at any one station fits a simple numerical model, described in *Flood Studies Report*, Volume II, Chapter 3.6:

$$\ln I - \ln I_0 = -n \ln (1 + BD)$$

where I is the rainfall intensity (mm/h),
I_0 is the rainfall intensity for very short durations (viz. 15 s),
D is the duration in hours,
B and n are factors which are constant for any particular location.

Values of I_0 range from 175 mm/h at stations in south-east England to less than 100 mm/h in Scotland, while n ranges from 0·77 in south-east England to less than 0·60 in mountainous parts of Scotland, and B ranges from 15 in the drier parts of the country to more than 30 in wetter, more mountainous regions.

4. ESTIMATION OF THE MAGNITUDE OF EVENTS WITH OTHER RETURN PERIODS

It is usually necessary to know the magnitudes of rainfall events with return periods longer than 5 years. The rate of increase of rainfall with return period varies from station to station, reflecting the details of the heaviest falls at each station. However, when dozens of stations are gathered together into regions, the regional average rate of increase becomes more or less the same, wherever the region is. Because of this, rainfall data for the whole country were used to establish the ratios of the T-year event to the 5-year event, MT/M5, called the growth factor.

In Figure 3, drawn from Table 2.7 of *Flood Studies Report*, Volume II, the growth factor is shown against the magnitude of the M5 rainfall event: a single set of curves is sufficient to estimate rainfalls with return periods other than 5 years in widely different places, such as Cambridge and Snowdonia, even though their other rainfall characteristics are so different. For example, if the 6-hour M5 event in Snowdonia and the 24-hour M5 event in Cambridge are of the same magnitude, then the events with longer return periods, but still of these same durations, are also of the same magnitude.

In fact there are some small differences in growth factor from region to region; the differences between north and south are just large enough to justify treatment as two separate regions; England and Wales (Figure 3), and Scotland and Northern Ireland (not given)—see *Flood Studies Report*, Volume II, Chapter 2.3. Growth factors were calculated for return periods of up to 1000 years, with

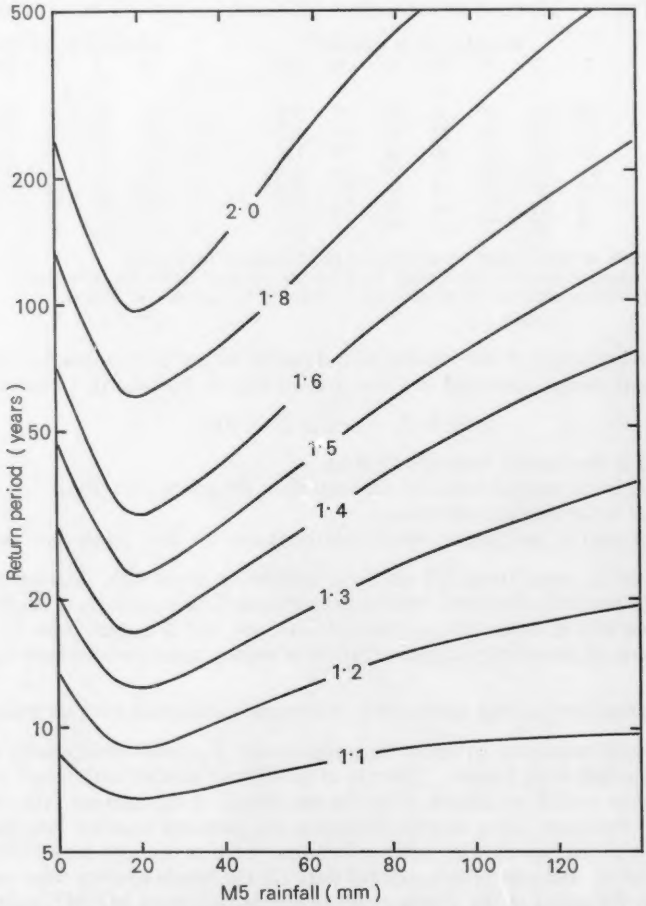

FIGURE 3—RATIO OF *T*-YEAR RAINFALL EVENTS TO 5-YEAR EVENTS PLOTTED AGAINST 5-YEAR RAINFALL (M5) AND RETURN PERIOD; SUITABLE FOR ANY POINT IN ENGLAND AND WALES

rough estimates for as much as 10 000 years: quite clearly the larger the return period, the less confidence we have in the estimate. For further discussion of this, the reader is referred to *Flood Studies Report*, Volume II, Chapter 2.3.

5. MAGNITUDE OF A RAINFALL EVENT OVER AN AREA

Engineers are often more interested in the magnitude of an areal rainfall event over a given catchment than in a point event such as those just described. To meet this requirement, areal reduction factors have been calculated, which depend on the size of the area and the duration of the event. When an areal reduction factor is multiplied by the value for the point rainfall event, the

product gives the magnitude of the areal rainfall event with the same duration and the same return period. It must be emphasized that this type of areal reduction factor is used both here and in the *Flood Studies Report*; it is not applicable to individual point-centred storms, but is for catchments which are independent of storm location.

The factor is smallest for small durations and over large areas, approaching unity as the area becomes smaller and the duration larger. Some point-centred reduction factors for the country were produced by Holland (1964), but the factors needed here for this kind of calculation are very different from Holland's. A graph for areas of size between 10 and 2000 km² is shown in Figure 4, which is based on *Flood Studies Report*, Volume II, Chapter 5.2.

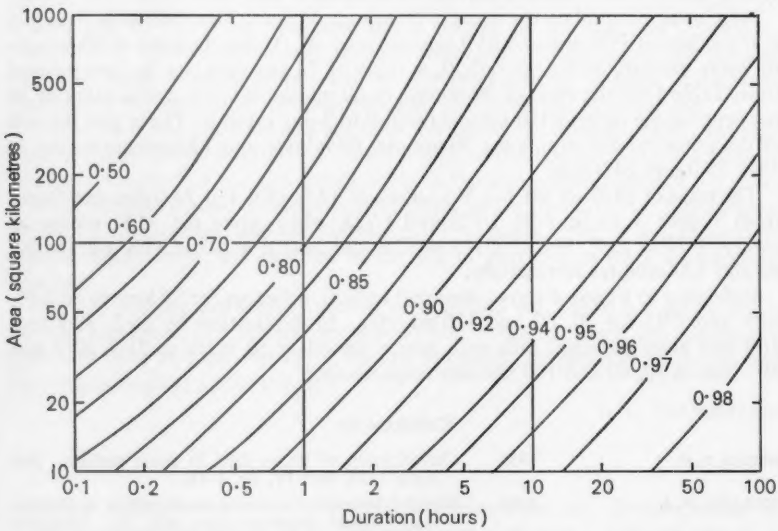

FIGURE 4—AREAL REDUCTION FACTORS: RATIO OF THE AREAL RAINFALL TO THE POINT RAINFALL OF THE SAME DURATION AND RETURN PERIOD

6. SIMPLE EXAMPLES

Example 1

An engineer asks for the magnitude of the 7-hour, point rainfall events in Wellingborough, Northants with return periods of 5, 10, 20 and 100 years.

Wellingborough is found on a map and the national grid reference noted (NGR SP 8968). The 60-minute M5 map is examined (preferably a larger version than Figure 1—copies are available in the Meteorological Office) and a value of about 19·2 mm read off at the appropriate grid reference. Similarly the 2-day map is examined (preferably a larger version than Figure 2—copies are available in the Meteorological Office) and the value of about 44·8 mm read off. Using the ratio of 60-minute to 2-day rainfall, 19·2/44·8 = 43 per cent, a value of 67 per cent can be interpolated from Table I for the ratio of 7-hour to 2-day rainfall. This gives a value for the 7-hour M5 as about 30·0 mm.

Further estimates can now be made of the magnitude of 7-hour rainfall events with longer return period. Figure 3 is a general diagram for England and Wales, showing the ratio of the MT event to the M5 event, plotted against M5 values. Values are read off for M5 = 30·0; MT/M5 is 1·21 when $T = 10$, 1·41 when $T = 20$ and 1·97 when $T = 100$ years. Multiplying the M5 value of 30·0 mm by these factors gives 36·3, 42·3 and 59·0 mm for the magnitudes of the 10-year, 20-year and 100-year 7-hour rainfalls respectively at Wellingborough.

Example 2

An engineer asks for the magnitude of the 30-minute, 60-minute and 120-minute rainfall events with return period of 50 years over a catchment of area 15 km^2 centred near Axminster, Devon (NGR SY 2998).

Axminster is found on the maps of 60-minute M5 and 2-day M5 as in Example 1, the values of 19·0 mm and 63·0 mm are read off. Using the ratio of 60-minute to 2-day rainfall, 19·0/63·0 = 0·30, a value of 78 per cent can be interpolated from Table I for the ratio of 30-minute to 60-minute rainfall, and a value of 38 per cent for the ratio of 120-minute rainfall to 2-day rainfall. These give the size of the point rainfall events for 30-minute, 60-minute and 120-minute events as 14·8, 19·0 and 24·0 mm.

The ratio of M50 to M5 for M5 values of 14·8, 19·0 and 24·0 mm are found from Figure 3 to be 1·70, 1·725 and 1·725, which gives the M50 events as $14{\cdot}8 \times 1{\cdot}70 = 25{\cdot}2$, $19{\cdot}0 \times 1{\cdot}725 = 32{\cdot}8$ and $24{\cdot}0 \times 1{\cdot}725 = 41{\cdot}4$ mm for 30, 60 and 120 minutes respectively.

Reference to Figure 4 shows the areal reduction factors for 15 km^2 to be 0·86. 0·89 and 0·92 for 30, 60 and 120 minutes. Multiplication by 25·2, 32·8 and 41·4 mm gives the areal falls with return period of 50 years as 21·7, 29·2 and 38·1 mm in 30, 60 and 120 minutes respectively.*

References

BILHAM, E. G. 1936 Classification of heavy falls in short periods. *Brit Rainf* 1935, Part IV, pp. 1–19.

HOLLAND, D. J. 1964 Rainfall intensity-frequency relationships in Britain. Hydrological Memorandum No. 33. Meteorological Office, Bracknell, Berks.

JENKINSON, A. F. 1976 Extreme value analysis in meteorology. 4th Conference on Probability and Statistics in Atmospheric Sciences. American Meteorological Society, Tallahassee, Fla, November 1975. Boston, Mass, pp. 83–89.

KEERS, J. F. AND WESTCOTT, P. 1977 A computer-based model for design rainfalls in the United Kingdom. *Scient Pap, Met Off*, No. 36.

Meteorological Office 1975 Natural Environment Research Council. *Flood Studies Report*, Vol. II, Meteorological Studies. London, NERC.

* Note that the application of the methods to larger catchment areas, especially with varied topography, requires more care. Examples are given in *Flood Studies Report*, Volume II, Chapter 8.

REVIEWS

The measurement of airborne particles, by R. D. Cadle. 150 mm × 230 mm, pp. xi + 342, *illus.* John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1976. Price £13·85.

This book is written for scientists and engineers who have to sample airborne particles and to measure their concentration, size and shape. It gives illustrations and diagrams of instruments, the basic theory underlying them, and practical advice on their use. The emphasis is on commercially developed and marketed instruments, and the book will be helpful to anyone lucky enough to have dollars to spend on the generally high-class American instruments in the air pollution field. The treatment is clear and, although sometimes abbreviated, is adequate for the book's purpose and is backed by the standard references. There are no obvious omissions. Some readers may consider that space devoted to manufacturers' photographs and to the basic theory of such well-known instruments as the optical microscope could have been put to better use.

The book is not intended as a textbook on aerosols. Meteorological applications are only briefly referred to. There is a short discussion on the characteristics and evolution of the size distribution of the atmospheric aerosol but there is no discussion on the condensation of water or ice on particles. Holography receives 21 lines of text and two references. Two pages, inserted in a chapter on Optical Microscopy, are devoted to the use of particles to trace atmospheric motions.

Anyone starting work with aerosols or pollution will find this a useful introductory handbook to methods, instruments and to the literature, but meteorologists will need to look elsewhere for full discussion of physical principles and for meteorological applications.

A. C. CHAMBERLAIN

Physical principles of micrometeorological measurements, Developments in Atmospheric Science, 6, by P. Schwerdtfeger. 240 mm × 170 mm, pp. ix + 113, *illus.* Elsevier Scientific Publishing Co, PO Box 330, Amsterdam, The Netherlands. Price: Dfl 75.

There are a number of standard textbooks on micrometeorology but most provide little information on the use of instruments which make the specialized measurements necessary in micrometeorological investigations. Professor Schwerdtfeger's slender volume attempts to fill this gap: in his own words, the book 'has been designed to emphasize the physical basis of precise meteorological measurements, especially those necessary in determining processes relevant to the atmosphere's behaviour close to ground level'. The material of the book is based on a university course and a substantial part is occupied by a description of about thirty experiments intended to be carried out by students. The experiments themselves are used both to illustrate the practical aspects of measurements and as a means of developing some of the principles involved.

Chapter 1 is concerned with air temperature measurements and the transfer of sensible heat and deals, *inter alia*, with topics such as thermal inertia and heating by radiation of thermometers, and heat transfer from plane surfaces.

Chapter 2 discusses the determination of solar and terrestrial radiation and related topics including estimation of the solar constant, and albedo. The book continues with a brief discussion of atmospheric pressure, followed by a section on the measurement of humidity. Chapter 4 introduces the concept of eddy transfer, following on from wind speed measurements and interpretation of the vertical gradient of wind speed. The fifth chapter deals with heat conduction in the ground. The final chapter, which is on the modelling of thermal processes by electrical analogues, reflects a particular interest of the author but seems to be an inappropriate contribution in such a short book.

The general level of presentation is elementary enough for the pace of the volume to be describable as 'leisurely', but this has resulted in a rather superficial treatment of many topics, and significant omissions. As a result, the book fails to live up to the assertion on its jacket that it is of great value as a textbook and reference work for meteorologists. On the other hand, if its remarkable price can be ignored, it provides a useful introduction for newcomers to the field. However, potential readers should be warned that c.g.s. units are used in many places in the text. Also, the sections on wind profiles and turbulent transfers are sprinkled with loose statements which can scarcely provide the sound foundation of knowledge required by the student reader: for example, the implication that only in neutral conditions is the mean vertical velocity near the ground essentially zero (pages 59 and 60), that friction velocity is the geometric mean of the horizontal and vertical velocity fluctuations (implying perfect correlation between them) (page 60), that atmospheric turbulence is isotropic (page 60), that the wind velocity vanishes at a height above the ground equal to the roughness length, and that the roughness length over *developed* waves is dependent on wind speed (for which there is little evidence) (page 61), and that an array of only 100 buckets arranged on the ground upwind of a profile mast will produce, in neutral conditions, a fully modified logarithmic profile of wind speed up to a height of at least 4 m. Blemishes such as these significantly reduce the value of what is otherwise a useful addition to the micrometeorological literature.

N. THOMPSON

NOTES AND NEWS

Retirement of Mr R. Murray

Mr Robert (Roy) Murray, who retired on 28 April 1977, joined the Office as a Technical Officer in September 1939 after graduating at Edinburgh University with an M.A. degree in Mathematics and Natural Philosophy. After a short initial training period in London he went to Headquarters No. 221 Group (Coastal Command), Royal Air Force Donibristle, later Pitreavie, for forecasting duties. Early in 1941 he was posted to the Isle of Islay and remained there for about a year before proceeding to Northern Ireland for relief duties at a number of RAF Coastal Command units. His service in Northern Ireland concluded with a spell at RAF Headquarters and in March 1943 he was commissioned in the RAFVR and sent to India, joining HQ No. 221 Group initially in Bengal. Flt Lt Murray proceeded with this Group to Imphal, Manipur, in November of that year. He remained at Imphal for a year or so and throughout the Japanese siege. He then became the Senior Meteorological Officer with the

mobile combined Headquarters 14th Army and 221 Group and travelled by stages through Burma to arrive in Rangoon in mid 1945. On the termination of hostilities he filled the post of Senior Meteorological Officer Burma and was responsible for a number of units scattered throughout Burma, Siam and Indo-China. He was mentioned in dispatches at this time. In February 1946 Sqn Ldr Murray (as he then was) was repatriated and demobilized, and took up civilian duties in the Central Forecasting Branch (Met O 2) at Dunstable. He became a Senior Scientific Officer in September of that year and in 1950 he moved to the Forecasting Research Branch (Met O 21) where he did some first-class work in pioneering the understanding of the dynamics of jet streams which was reported in a classic paper. Promotion to Principal Scientific Officer followed in 1953 with a return to operational forecasting duties. In August 1956 he was posted to Aden to become the Chief Meteorological Officer, MEAF. Two years later he returned for a brief spell to a research post in upper-air climatology at Harrow (Met O 13) and subsequently went overseas again in mid 1959 to Cyprus to occupy the Chief Meteorological Officer post at Headquarters NEAF where he remained for the next four years before returning in August 1963 to the Synoptic Climatology Branch located at Bracknell. He spent the next decade in that Branch contributing to research in forecasting for periods of one month to a season. It is interesting to record that the first 30 day forecast issued to the public (for December 1963) correctly predicted a major change from an exceptionally warm November to an exceptionally cold December and that this was largely due to his confident prediction of an imminent block. Throughout his career in extended-range forecasting his approach was essentially a practical one based on a desire to establish the technique on a sound and objective basis. During this time he published some 30 papers on the detailed climatology of the British Isles, developing objective indices and rules for forecasting monthly and seasonal temperature and rainfall. He was awarded the L. G. Groves Memorial Prize for Meteorology in 1970 (jointly with R. A. S. Ratcliffe) for work relating ocean temperature to atmospheric circulation anomalies.

In May 1973 Mr Murray was promoted to Senior Principal Scientific Officer and took charge of agricultural meteorology and hydrometeorological work as an Assistant Director. He remained in this post until his retirement. During this period he successfully led efforts to establish and introduce computer-based techniques which enabled the services provided to the community in general, and the water and agricultural industries in particular, to be improved in quality, quantity and range. In the last year of his service he was actively involved in many aspects of work resulting from the 1975/76 drought.

There can be few left in the Service who have had as varied a career. It was not until the last 18 months that I came into day-to-day contact with him, and I would like to record my personal thanks for his informed advice and willingly tendered help. We wish Roy and his wife a long and active retirement.

N. E. RIDER

THE METEOROLOGICAL MAGAZINE

VOL. 106 NO. 1259 JUNE 1977

CONTENTS

NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

Complete volumes of 'Meteorological Magazine' beginning with Volume 54 are now available in microfilm form from University Microfilms International, 18 Bedford Row, London WC1R 4EJ, England.

Full size reprints of out-of-print issues are obtainable from Johnson Reprint Co. Ltd, 24–28 Oval Road, London NW1 7DX, England.

Issues in Microfiche starting with Volume 58 may be obtained from Johnson Associates Inc., P.O. Box 1017, Greenwich, Conn. 06830, U.S.A.

Printed in England by Heffers Printers Ltd, Cambridge
and published by
HER MAJESTY'S STATIONERY OFFICE

80p monthly **Annual subscription £10.68 including postage**

Dd. 497684 K16 6/77 ISBN 0 11 724712 X